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FIRE BLIGHT OF PEARS AND RELATED PLANTS

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FIRE BLIGHT OF PEARS AND RELATED PLANTS[1]

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THE SEVERITY OF BLIGHT (caused by *Bacillus amylovorus*) in the pear orchards of California in 1930 raised many questions which had not been answered by earlier work on this disease. The investigations which followed in this state, together with those of recent years in other states, have brought out a number of new facts which are assembled below. Since the earlier publications of this station are out of print, the essential information resulting from earlier investigations is also given.

SYMPTOMS OF BLIGHT

The disease affects all parts of the plant both above and below ground. The organism usually enters the tree through the blossoms and (less frequently) through the actively growing shoots, both of which rapidly shrivel and darken in color as though scorched by fire—hence the descriptive name fire blight. A characteristic milky to brownish sticky gum is frequently exuded from blighting parts (fig. 1). This exudate contains enormous numbers of bacteria.

The germ travels downward through the blossom spur or shoot into the branch, trunk, or root, on which a canker is formed, involving the bark usually in a circular or elliptical area, which may continue to enlarge until the entire tree is killed. In smooth bark the cankers may be distinguished by a somewhat darker color and cracking of the bark in later stages. On the surface of rough bark no evidence of the canker is likely to appear except the exudate, and this is often absent, especially in dry weather (fig. 7, p. 35). The interior of the affected bark at first appears only slightly water-soaked, later becomes mottled with reddish-brown blotches and lines, and finally becomes dark brown to black. Occasionally on an older branch, trunk, or root, the infection may extend in a narrow strip ("stringer") for some distance beyond the margin of the canker proper. These may be no more than ½ inch in width and apparently as much as several feet in length. They are seen more often in fall and winter and seem to extend downward toward the roots more often than upward.

Separate infections may appear in the leaves under conditions of high

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atmospheric humidity. These seldom extend beyond the production of large irregular spots in the leaf blade.

The symptoms on plants other than pear are essentially similar, except that the color of blighted parts is sometimes much lighter.

Distinguishing Blight from Blast.—Another bacterial disease of pear in California may at times resemble blight so closely as to be almost indis-

Fig. 1.—Blighting blossom cluster showing drops of bacterial exudate on a young fruit and at the base of a shoot.

tinguishable from it (fig. 2). This disease, designated as blast, is caused by organisms similar to those of blast of citrus and gummosis of stone fruits (45, 50, 73).[4] Blast may usually be distinguished from blight by the following: On blossom spurs, blast seldom extends more than 1 or 2 inches into the spur. In cankers, the bark is often light brown to tan in color and the outer bark becomes loosened in scales in older cankers. No bacterial exudate has been found to be associated with this disease.

PLANTS SUSCEPTIBLE TO FIRE BLIGHT

The blight problem in California is peculiar in that the range of susceptible plants is distinctly different from that in other areas in which the disease occurs. A large number of rosaceous plants are now growing in the state in the wild, for fruit, and as ornamentals, and the num-

[4] Numbers in parentheses refer to papers in "Literature Cited," at the end of this bulletin.

ber is rapidly increasing. The resistance or susceptibility of these plants to blight is of importance for several reasons: they may serve as a source of the blight germs for pear orchards; some of them may be useful as stocks for pear or apple; some are sufficiently susceptible as to render them unsuitable for planting as ornamentals.

Table 1 and the discussion which follows include information drawn

Fig. 2.—The blast disease of pear, showing localized type of injury in blossom cluster and cluster base.

from a considerable number of reports (2, 3, 5, 9, 14, 17, 19, 21, 24, 33, 34, 36, 38, 40, 46, 48, 52, 61, 62, 70, 71, 72), several of which contain reviews of the earlier work.

Since natural blight infection has not been observed on any plant outside of the rose family,[5] this work has been limited almost entirely to that family. Within the family, plants were selected on three principal bases: occurrence in the wild, abundance in cultivation, and nearness of relation to the pear. In a few instances in which native species were not available, other species of the same genera were included.

Some earlier work (62) on this phase of the problem in which one of the writers participated, was done for the most part in the field. The results of inoculations in the field indicate more exactly the response of a plant to natural infection; but inoculations in the greenhouse have seemed to provide the more severe test of resistance and have been used

[5] Infection has been produced by artificial inoculation on walnut (49) and on persimmon (62).

for most of the recent work. Unless otherwise noted, only vigorously growing shoots (or petioles of herbaceous plants) were inoculated. Flower parts of some species appear to be more susceptible than shoots. Usually 10 to 25, but occasionally fewer, inoculations were made on shoots of each species.

TABLE 1

SUSCEPTIBILITY TO BLIGHT IN THE SUBFAMILIES OF THE ROSACEAE (ROSE FAMILY)*

Subfamily and genus	Species tested	Number susceptible	Number overwintering the organism	Subfamily and genus	Species tested	Number susceptible	Number overwintering the organism
Spiraeoideae				Rosoideae			
Lyonothamnus	1	—†	—†	Kerria	1	—†	—†
Physocarpus	1	—	—	Rhodotypos	1	—	—
Spiraea	7	2	—	Rubus	1	—	—
Sorbaria	1	—	—	Geum	1	—	—
Aruncus	1	1	—	Potentilla	1	—	—
Quillaja	1	—	—	Fragaria	2	2	—
Kageneckia	1	1	—	Fallugia	1	—	—
Exochorda	1	—	—	Cowania	1	1	—
Holodiscus	1	1	—	Dryas	1	—	—
				Cercocarpus	1	—	—
Pomoideae				Adenostoma	1	—	—
Cotoneaster	35	24	1	Chamaebatia	1	—	—
Mespilus	1	1	—	Margyricarpus	1	—	—
Pyracantha	5	5	4	Acaena	1	—	—
Crataegus	18	7	1	Sanguisorba	1	—	—
Osteomeles	1	1	—	Rosa	12	3	—
Sorbus	4	2	1				
Aronia	1	1	—	Prunoideae			
Photinia	5	4	1	Prunus	27	16	—
Stranvaesia	1	1	—	Prinsepia	1	—	—
Eriobotrya	1	1	1	Osmaronia	1	—	—
Docynia	1	1	—				
Chaenomeles	3	3	—				
Cydonia	1	1	1				
Raphiolepis	2	2	—				
Pyrus	39	39	32				
Amelanchier	2	2	—				
Peraphyllum	1	1	—				

* A considerable part of the specific record of overwintering is drawn from a letter from Mr. F. C. Reimer written February 20, 1934.

† Dashes indicate that no susceptibility or overwintering was found.

In some of the species studied, considerable variation has been noted between different individual plants both in susceptibility to blight and in appearance. This is due in large part to the practice of growing the plants from seed. A few nurserymen, however, are maintaining uniform stock of the most desirable types of such plants as *Cotoneaster* and *Pyracantha* by the use of cuttings and grafts.

The list of plants known to be susceptible to blight has grown to its present size (more than 120 species) over a long period of years through the activities of many workers in diverse situations. It is not possible

therefore to compare in detail the numerous species as to degree of susceptibility. A step in this direction may be made, however, by arranging the available information in accordance with a natural classification (Rehder, 39) of the plants. It will be seen in table 1 that in the subfamily (Pomoideae) which contains pear and apple, all the genera contain susceptible species and a much greater proportion of all the species tested in this subfamily are susceptible. Overwintering the blight organism in any species of the other subfamilies is unknown, and the disease in these seldom, if ever, affects the older parts of the plant. Thus, while many species have been added to the list of susceptible plants in recent years, these actually serve to indicate more clearly than was formerly apparent that the disease in severe form is limited to plants rather closely related to pear and apple.

Of the 27 native California species tested, 7 became infected. Thus far natural infection seems to have been found in only one of these, the toyon, and that only under cultivation.

In the following notes, the susceptible species for which no earlier records have been found are marked by an asterisk. The F.P.I. numbers indicate plants distributed by the Office of Foreign Plant Introduction of the United States Department of Agriculture.

Amelanchier.—The native western serviceberry, *Amelanchier alnifolia** became infected readily in 8 of 10 shoots but the blight stopped within 2 to 3 inches of the inoculated tips.

Aronia.—The red chokeberry, *Aronia arbutifolia** was less affected than the preceding, only 2 of 10 inoculated shoots showing symptoms.

Aruncus.—*Aruncus sylvester** (goatsbeard, native) blighted readily in very young petioles but not in older parts.

Chaenomeles.—The flowering Japanese quinces, *Chaenomeles japonica** and *C. lagenaria* are sold under the names of a number of varieties, only a few of which have been tested for susceptibility to blight. Both species contain some susceptible varieties though no infection has extended more than 4 or 5 inches in the limited tests thus far conducted. The Chinese quince, *C. sinensis,* is also susceptible (62) but is not commonly planted.

Cotoneaster.—This genus contains over 40 species, many of which have been introduced into California. Inoculations past (48, 62) and present have been made on shoots of about 35 species. Twenty-four of these have shown slight to marked susceptibility to blight. The tests were not sufficiently extensive, except with a few species, to give more than a general view of the degree of susceptibility of the various species. Moreover, such information as is available cannot apply to all individual plants of the species because of variation and hybridization.

Cotoneaster pannosa is apparently the most susceptible of the species studied and is usually consistent both in appearance and susceptibility. *C. salicifolia* varies widely in appearance and susceptibility and is sometimes severely blighted. Both susceptible and highly resistant plants are found in *C. frigida* but most of those studied have been relatively resistant. *C. horizontalis* is moderately susceptible after inoculation and *C. microphylla* is slightly so. Natural infection has not been seen by the writers on either of these. One collection of *C. harroviana* is at hand which is uniform in appearance and virtually immune to blight. Plants have been seen under this name, however, which are obviously hybrid and some of which are readily infected. *C. dielsiana** and *C. lactea** are other species of which susceptible specimens have been obtained from one source and highly resistant or immune forms from another. No infection has been produced on *C. franchetii* in a considerable number of trials nor has any been found on plants of this species in nature.

Other species of less interest at present, the shoots of which have blighted after inoculation are: *Cotoneaster acutifolia villosula,* C. adpressa, C. aldenhamensis** (F.P.I. 76730), *C. ambigua,* C. apiculata,* C. bullata floribunda,* C. buxifolia vellaea** (F.P.I. 56304), *C. dammeri radicans* (F.P.I. 52677), *C. glabrata,* C. lindleyana,* C. nitens,* C. parnayi** (apparently of local origin), *C. prostrata, C. rotundifolia,* C. tomentosa,* C. zabelii.** The infection was slight on several of these, notable among which were *C. acutifolia villosula, C. ambigua, C. bullata floribunda, C. glabrata.*

The shoots of the following species remained free from infection in similar tests: *Cotoneaster affinis bacillaris, C. decora* (F.P.I. 64253), *C. glaucophylla, C. hebephylla, C. henryi, C. hupehensis, C. melanocarpa, C. newryensis, C. praecox, C. racemiflora songarica.*

Cowania.—The cliff rose, *Cowania mexicana stansburiana,** became slightly infected in young seedlings.

Crataegus.—The English hawthorns, *Crataegus oxyacantha* and *C. monogyna,* are distinctly the most susceptible to blight of the hawthorns which have been tested (61) and approach the pear and apple in degree of susceptibility. The single native kind, *C. douglasii,* or western black hawthorn, has shown no infection in inoculated shoots.

Cydonia.—The susceptibility of the cultivated quince (*Cydonia oblonga*) is well known. It is of importance for the reason that the blossom period often overlaps that of pear and apple and increases the chance for dissemination to these.

Docynia.—The species *Docynia delavayi** (F.P.I. 44677) used in this work, like the others of the genus, is rarely planted in California and does not now present a problem to orchardists. It is of interest chiefly

because of its close relation to the quince and pear. Young shoots were readily infected.

Eriobotrya.—The seedling loquats commonly planted as ornamentals and for fruit seem to vary considerably in susceptibility to blight but no immune plant has been found. The three named varieties, Advance, Premier, and Thales, in very small-scale tests were all about equally affected.

Holodiscus.—The native cream bush, *Holodiscus discolor,** becomes infected readily upon inoculation in vigorous shoots but the blight usually stops within 2 to 3 inches of the tips of shoots.

Kageneckia.—*Kageneckia oblonga,** in a very limited test, became blighted in all of several young shoots.

Osteomeles.—Shoots of *Osteomeles anthyllidifolia** blighted slowly to 3 or 4 inches from the tips.

Peraphyllum.—The single native species *Peraphyllum ramossimum** is probably rare in all orchard districts. Young shoots blighted quickly after inoculation.

Photinia.—*Photinia serrulata* has remained immune to infection in these tests. *P. deflexa** (slow growth rate) blighted slowly and *P. glabra** somewhat more rapidly; parts as much as 3 or 4 inches in length were involved with the latter. The last two species are rare in California gardens at present.

The toyon or Christmas berry, *Photinia arbutifolia,* blights freely under cultivation and occasionally carries the blight bacteria overwinter. Fortunately, blight seldom if ever is seen on these plants in the wild.

Prunus.—Natural fire-blight infection has been reported on apricot, cherry, plum, and prune, but apparently infection in these is rare. The writers have seen natural infection on only one species, *Prunus lusitanica,** and this is highly resistant. Apparently no reports have been made of blight in the above-named orchard fruits in California. Slight infection followed inoculation of very young seedlings of the native holly leaf cherry, *P. ilicifolia.** *P. fremontii* (native desert apricot) is highly resistant if not immune. Of the 25 *Prunus* species tested by inoculation in California, including earlier experiments (62), none became blighted to more than 3 inches from the point of inoculation.

Pyracantha.—*Pyracantha angustifolia* and *P. formosiana* (now called *P. koidzumii*) are sufficiently susceptible so that plants several years old may be entirely killed by blight. All of the species except *P. angustifolia* vary considerably in susceptibility of individual plants but most plants of *P. coccinea lalandi* (Laland firethorn), *P. crenulata* (Nepal firethorn), and *P. gibbsii yunnanensis* (Yunnan firethorn) which have been inoculated are distinctly less susceptible than those of *P. angustifolia.*

There is need for selection of better and more resistant forms in all these species. Hybridization will probably be necessary with *P. angustifolia.* Some interesting selections such as the Rogers Orange firethorn have already appeared and some of them are relatively resistant.

Pyrus.—Little is available to add to the exhaustive work of Reimer (40) on the susceptibility of pear species. All species studied thus far are found to contain at least some distinctly susceptible individuals although some species of oriental origin are much more resistant as a whole than others, such as the French pear (*Pyrus communis*), which includes all the commonly cultivated varieties of California. The writers have inoculated the evergreen pear, *P. kawakamii,** and the ornamental crab apple, *P. spectabilis,** both of which blighted freely. The susceptibility of pear varieties is referred to under the heading "Control."

Raphiolepis.—Natural blossom infections were found in appreciable numbers in one planting of *Raphiolepis umbellata** at Berkeley in 1933. The shoots of this species so far as tested, however, are distinctly resistant. Shoots of *R. indica* became infected more readily in earlier trials in the field (62).

Rosa.—Slight to moderate susceptibility has been shown (36) for the species *Rosa blanda* and *R. rubiginosa* and for several varieties, particularly the Tausendschön. In the course of this work, the four native species, *R. californica* (California wild rose), *R. gymnocarpa* (wood rose), *R. nutkana,* and *R. spithamea* (ground rose) were inoculated in shoots. The shoots of *R. nutkana* were in a rather poor state of vigor. No infection resulted in these or in *R. hugonis, R. longicuspis,* or *R. stellata.* Among the rose stocks, slight killing occurred around the points of inoculation of *R. multiflora** (11 out of 40 shoots) but not on *R. manettii, R. odorata,* or Ragged Robin. Young unopened buds of Ragged Robin, Cecil Bruner, and Independence Day were sometimes killed after inoculation, but the blight did not extend beyond the pedicel. Older buds (still unopened) were distinctly more resistant. Belle of Portugal shoots reacted to inoculation about as those of *R. multiflora.* No infection was obtained in shoots of the varieties Briarcliff, Cecil Bruner, Hadley, Independence Day, and Premier Supreme. Susceptibility appears to be slight at most in the roses tested thus far.

Spiraea.—*Spiraea vanhouttei* has been shown to be slightly susceptible to blight (17). The native species *S. densiflora** blighted readily in very young shoots (12 out of 25) but the infection did not advance in any of these for as much as 2 inches. Another native species, *S. douglasii,* remained unaffected or virtually so after inoculation, as did *S. bella* (F.P.I. 47801) and *S. salicifolia* (F.P.I. 72417).

Stranvaesia.—*Stranvaesia davidiana* has been found to be susceptible

in New Jersey (72). Specimens of this species from two sources (one of them F.P.I. 58620) were invaded to about 2 inches from the points of inoculation (5 out of 21 shoots). Another form (F.P.I. 80371) not bearing a specific name appeared to be somewhat more susceptible.

Sorbus.—The European and American mountain ashes (*Sorbus aucuparia* and *S. americana*) have been on the list of blight-susceptible plants for many years (9, 14). Inoculations on the European form, both in a former study (61) and in the present one, produced at most only slight infection. At least some plants of this species are highly resistant. The native western mountain ash, *S. sitchensis,* has remained entirely free from blight after repeated inoculation. *S. domestica* in rather poor growth condition failed to become blighted after inoculation.

Additional Noninfected Species.—Those species which failed to become infected and which are not mentioned in the discussion elsewhere are as follows: *Lyonothamnus floribundus* (island ironwood or Catalina lyonshrub), *Physocarpus capitatus* (ninebark), *Sorbaria arborea, Exochorda grandiflora* (pearlbush), *Quillaja saponaria, Kerria japonica, Rhodotypos tetrapetala, Rubus parvilflorus* (thimbleberry), *Geum chiloense, Potentilla fruticosa* (shrubby cinquefoil), *Fragaria chilensis, Fallugia paradoxa* (apache plume), *Dryas suendermannii, Cercocarpus betuloides* (hard tack), *Adenostoma sparsifolium* (ribbonwood), *Chamaebatia foliolosa* (bear mat), *Margyricarpus setosus* (pearl-fruit), *Acaena microphylla, Sanguisorba* sp., *Prinsepia sinensis, Osmaronia cerasiformis* (oso berry).

SOURCES OF BACTERIA FOR THE FIRST SPRING BLIGHT INFECTIONS

Low ebb in the annual cycle of fire blight is reached in late winter and early spring before susceptible plants come into blossom. In this period complete eradication of the blight bacteria may be most nearly achieved. It is desirable therefore to consider all of the possible places where the organism may be found at this time. For any given plant, the sources of the bacteria for the first spring infections may be not only those in which the bacteria have overwintered but also earlier flowering plants of other kinds in which the organism has already begun to build up.

Bacteria in the Soil.—Contrary to prevalent opinion Ark (1) has recently shown that the blight organism is able to survive in the soil for considerable periods. In laboratory tests the bacteria remained alive for 54 days in previously sterilized soil and for 38 days in unsterilized soil. In artificially contaminated samples, buried in the field at Berkeley, the bacteria persisted for 9 months in sterilized (and sealed) soil but could not be recovered from unsterilized soil after 8 months.

In orchard soils collected near blighted trees, the blight organism was found rather frequently during the growing season of 1931 and up to the first heavy rains in November. It was not recovered from the soil samples taken in December. In the winter of 1932–33, twenty stations for sampling were selected in an orchard at Courtland. These were all directly beneath branches which had borne active cankers in 1932. Early in December the cankers were removed or treated with an experimental solution which later proved to be ineffective in some cases. Thus, the bacteria found in the soil at later dates may have washed down from the tree shortly before sampling. The organism was found in soil from 9 stations on December 1, from 10 on December 30, from 4 on January 30, from 2 on February 28, and from 1 on March 31.

It will be seen that the number of organisms at the end of February is very greatly reduced and at the end of March is near the vanishing point. These results coupled with those of 1931–32 suggest that the soil is probably unimportant in overwintering the bacteria. The possibility of direct infection of the roots from the soil during the growing season will be considered later.

The Beehive as a Possible Source of the Organism.—More than ten years ago in Ohio (16) the blight organism was found to be able to survive in honey for at least 3 days, and later workers (29, 59) extended this period to several weeks. Investigation in the laboratory at Berkeley showed further that when bacterial exudate from pear is spread on the surface of honeycomb the bacteria may be recovered alive after three months. In recent New York investigations (35) the organism was able to survive longer on the surface of honeycomb in a very dry atmosphere than in a relatively moist atmosphere. This indicates that the bacteria survive in a dormant condition since moisture is necessary for their active growth processes.

All of the experiments referred to thus far were made in the absence of bees. Both the Ohio and New York investigators attempted to isolate the fire-blight organism from the beehive in the early spring. In New York the hives were artificially contaminated in the preceding November. The results were negative in all cases. One author (42) reported having obtained the blight bacteria from the beehive during the dormant season but his later work (44) did not confirm this report.

The writers, in coöperation with the Pacific States Bee Culture Field Laboratory at Davis, California, have made a considerable number of cultures involving material from various parts of the hive and a rather large number of individual bees. The bees were taken on 28 different dates from April 16, 1931, to April 17, 1933, mostly at Davis (table 2). Some of the bees were taken from blossoms but most of them directly

from the hive, either at the entrance or from the interior. The hives were located near pear trees in all cases.

The blight organism was not obtained from the hive material in any case (550 cultures) and from the bees only when blossoms of fruit trees were available to the bees. Fruit trees of one kind or another are in blossom at Davis from the end of January to May or later. Loquat and sometimes flowering quince may be in blossom in December. The bees of

TABLE 2

RESULTS OF CULTURING OF BEES FOR BACILLUS AMYLOVORUS

Month	Bees from hive		Bees from blossoms	
	Total numbers	Number contaminated	Total numbers	Number contaminated
January	22	2	....	....
February	40	3	62	0
March	239	7	56	0
April	1,354	1	184	26
May	136	0	69	21
September	510	0	....	....
December	29	0	....	....

several lots were taken from hives which had been confined in tents with inoculated pear blossoms.

The evidence above and some of that to follow (under the heading "Dissemination") indicates that the blight bacteria do not survive for long in the beehive either in winter or summer. While avoiding the transfer of bees from severely blighted to blight-free orchards is a reasonable precaution, there is no direct evidence to date that the bacteria are ever returned to the blossoms of fruit trees after they have been carried into the hive (63).

Unblighted Blossoms of Miscellaneous Plants as a Source of the Bacteria.—It has been shown in Ohio (16) that the blight bacteria may remain alive for at least 5 days in the blossoms of such plants as peach, plum, and cherry even when these blossoms do not develop blight. The writers have found the nectar of plum to be a favorable medium for the growth of the blight bacteria when brought into the laboratory.

It is reasonable to expect therefore that in some seasons the bacteria may build up in the early blossoms of fruit trees and other plants from which they may be transferred to the later-flowering sorts such as pear and apple. With this possibility in mind, over 250 blossoms were cultured from February 11 to March 21, 1932, representing 18 species and varieties of plants which come into blossom before or during the blossom period of pear. The blight organism was found in only 1 case, in a single

culture from flowering quince. From December 21, 1932, to March 23, 1933, five lots of flowering quince blossoms were cultured. The blight organism was not found in these nor in blossoms of almond, nectarine, peach, and plum tested in February and March, 1933. Both 1932 and 1933 were years of little blight in the districts from which the above blossoms were collected. Further work on this point is desirable in years when blight is more prevalent.

Blighted Plants Other Than Pear as Reservoirs of the Bacteria.—The total number of known susceptible plants (treated elsewhere in this bulletin) is so large that it will not be feasible for many growers and blight operators to become acquainted with all of them. Fortunately most of these do not seem likely to contribute to the blight in pears. Overwintering in California has been seen by the writers on only eight species other than pear and apples. These are *Cotoneaster pannosa, Crataegus oxyacantha* (English hawthorn), *Eriobotrya japonica* (loquat), *Photinia arbutifolia* (toyon), *Pyracantha angustifolia, P. crenulata, P. formosiana* (*P. koidzumii*), and *P. gibbsii yunnanensis.*

Among these, all except loquat come into blossom distinctly later than the pear, and most loquats complete the blossom period before pear blossoms begin to open. Since the principal avenue of dissemination is from blossom to blossom, the differences in blossom periods greatly diminish the chance of transfer from other susceptible plants to the pear. Exceptions are the apple and quince, including the flowering types.

Certain other susceptible kinds as *Pyracantha formosiana* (*P. koidzumii*), *Cotoneaster horizontalis,* and *Raphiolepis umbellata* produce scattered blossoms over a long period which may coincide in part with the blossom period of pear. However, such plants of this sort as are known to the writers either have not been widely planted or have not often become blighted in nature.

While much is yet to be learned concerning the blossoming habit and degree of susceptibility of the numerous rosaceous plants, it is the opinion of the writers that not more than the following, of the kinds mentioned above, are likely to serve as sources of bacteria for the production of blossom-blight infection on the pear: apple, including the crabs; loquat; quince, including flowering types; and possibly some of the cotoneasters and pyracanthas.

The Pear as a Spring Source of Blight Bacteria.—Even in years of the widest dissemination of the blight organism such as 1930 there is much evidence to indicate that the pear tree itself is the principal source of the bacteria. One may cite for example the fact that in 1930 certain orchards in the heart of the most severely affected districts remained virtually free from blight throughout the season. These were

orchards in which the holdover cankers had been reduced to a minimum if not actually eliminated.

In years of less severe blight, as 1932 and 1933, the source may be traced rather easily, since the initial dissemination is often no more than one or two rows distant from the tree which bears the holdover canker. This fact is so apparent that some blight operators make use of it in locating the cankers which have escaped notice during the preceding winter. An illustration may be taken from an orchard at Marysville where in 1932

TABLE 3

OVERWINTERING OF BACTERIA IN BLIGHTED PEAR TWIGS AS DETERMINED BY CULTURING ON THE DATES INDICATED

Variety	Locality	Date collected	Number of twigs	Number positive	Per cent active	Diameter, inches
Bartlett	Walnut Grove	1–23–32	15	6	40	3/16–9/16
			13	7	53	4/16–8/16
Bartlett	Courtland	1–29–32	64	23	35	2/16–7/16
Howell	San Jose	2– 6–32	15	2	13	4/16–6/16
Bartlett	Isleton	2–14–32	35	9	25	3/16–8/16
Bartlett	Courtland	2– 1–33	44	21	51	3/16–7/16
Bartlett	Walnut Grove	2– 1–33	48	40	88	3/16–5/16

an exact record was kept by Arthur Worledge of all blighted spurs removed during several weeks following the blossom period. From a large tree which bore a holdover canker, a total of 166 blighted spurs were removed. From three of the adjacent trees, 39, 19, and 95 spurs, respectively, were cut. From another tree in the second row from the source, 36 blighted spurs were taken. Not more than 1 or 2 affected spurs were found in any other tree in the vicinity.

The best blight operators known to the writers freely admit that complete eradication of all holdover cankers is rare, if it is ever accomplished. In counts in a number of orchards of the Sacramento Valley in January, February, and March of 1932, after the control work for the winter had been completed, the prevalence of holdover cankers varied from 0 to 10 or 20 for each 100 trees.

The foregoing has particular reference to the cankers which appear on the trunks and larger branches of trees. These are a greater menace to the orchard than cankers on small branches and twigs for the reason that more of the former survive the winter and a greater proportion of them will produce ooze in the early spring. The bacterial ooze has been seen on such cankers in the Sacramento Valley in every month of the winter.

The fact that small, blighted twigs of the preceding season may carry

the bacteria through the winter and in considerable abundance in some years is by no means new (7, 36, 54) but is too often disregarded. Table 3 shows the results of culturing such twigs. All the lots represented in the table except the first were taken as they came, whether or not the blight appeared to be active. The organism was isolated in some cases from twigs in which the blight appeared to be permanently stopped. That is, it was not possible to determine by symptoms, such as the cracking of the bark, whether the organism had died out in any given infection. All twigs in the two 1933 lots and many of those in other lots were shoots of the preceding season which had borne terminal clusters of late blossoms. The infection evidently took place in these blossoms during 1932 between the latter part of August and the middle of October, thus carrying the infections into the winter in a relatively young and active condition.

All of the evidence available at present indicates that the pear tree itself is the source of bacteria for the first spring infections on the pear in the great majority of cases.

DISSEMINATION OF THE BLIGHT ORGANISM

Long-Distance Transfer.—The possible spring sources of blight bacteria are dealt with in the preceding section of this bulletin. The cases in which convincing evidence is presented of transfer of the organism over considerable distances are rare. In one instance (61) the initial infection in a New York pear orchard seemed certainly to have resulted from infected pear trees about 200 yards from the margin of the orchard. Again in Indiana (15) dissemination evidently took place from pear to apple over a distance of ½ mile. Natural spread of the organism over greater distances is probably exceptional. Certainly the organism is seldom carried over great natural barriers, as witness the fact that the occurrence of the disease outside of North America has not been clearly proved except in New Zealand. In the earlier days of less careful handling of nursery stock, this would seem to have been one of the means of long-distance dissemination. Exporters of fresh pears and apples may well consider in this connection the fact (30) that apple fruits inoculated on the tree may occasionally carry the blight bacteria well into the storage period without developing external symptoms.

Dissemination from Holdover Cankers to Blossoms.—The transfer of the blight bacteria from one place to another is a simple mechanical process and is known to take place in a variety of ways. The chief problem here is to determine the relative importance of the various means of dissemination (fig. 3). Earlier workers (22, 56, 57, 68) attributed the first spring or primary dissemination of the blight bacteria to insects of various kinds, among which were flies, ants, click beetles, and tarnished

plant bugs. Some of the more recent investigators (16, 32) have emphasized the importance of rain as a vector; but this agent has not been shown to carry the bacteria to blossoms other than those directly below the holdover canker or very near (35). At one time or another the following kinds of insects have been observed to feed on the bacterial exudate from blight cankers and most or all of these may be seen on the blossom clusters of pear or apple: ants, aphids, beetles, codling moth, flies, wasps, and yellow jackets.[6]

Flies and ants have been shown by direct experiment to carry the blight bacteria from cankers to blossoms in New York and California

Fig. 3.—Diagram of the common modes of dissemination. The bacteria are first carried from holdover cankers (*A*) to the blossoms by flies (*B*), ants (*C*), etc. Then blossom-visiting insects, including bees (*D*), flies, and many others, carry the organism to other blossoms such as those at *E*. (Drawing by John R. W. Wilson.)

(35). The honey ant is abundant in fruit-tree blossoms in some districts of California and at least one species of *Formica* has been found feeding in pear blossoms at Davis. Flies of many kinds may be seen around the trunks of fruit trees and in blossoms. Flies in general are attracted by fermented material, and this no doubt accounts for the often observed congregation of flies around oozing cankers. The attraction of blighted material for flies is well illustrated in the results of a test made by Victor Wegner near Courtland. Two fly traps were baited, one with molasses, one part in three parts of water, the other with moistened chips from an

[6] Ants—*Formica fusca, F. pallide-fulva, Lasius niger* (35), *Prenolepis imparis* (honey ant).

Aphids—*Aphis avenae* (grain aphid) (7), *A. pomi* (green apple aphid) (35).

Beetles—*Melanotus oregonensis* (click beetle) (Leslie M. Smith, unpublished); *Scolytus rugulosus* (shot-hole borer) observed by many boring in older cankers (23), sometimes seen boring into oozing cankers.

Codling moth—*Carpocapsa pomonella;* reported in conversation by Victor Wegner.

Flies—*Drosophila funebris, Hylemia antiqua* (onion maggot), *H. lipsia, Musca domestica* (house fly), *Muscina assimilis* (squash root maggot), *M. stabulans, Pegomyia calyptrata* (35).

Wasps—*Vespula* sp. (Leslie M. Smith, unpublished).

Yellow jackets—*Polistes* sp. (Leslie M. Smith, unpublished).

active blight canker. After these were kept for a period in comparable positions, the first trap contained 78 flies and the second 786.

Bees have not been shown to feed on the bacterial exudate even when placed directly on the oozing canker (61, 35).

Dissemination from Blossom to Blossom.—Under favorable weather conditions (warm and humid) the organisms increase rapidly in the blossoms and are quickly transferred to other blossoms by the numerous insects which visit the blossoms for nectar or pollen (fig. 3). A very large part of the increase in blight infections is to be expected at this time. The long duration of the blossom period and particularly the tendency toward production of numerous scattered blossoms for several weeks after the regular blossom period in California, greatly increase the opportunities for dissemination as compared with colder regions. Among the more important insects which may play a part are bees, including both the honeybee and wild forms, flies of many kinds, and probably ants, beetles, and moths. It is known that most, if not all, of the numerous kinds of moths are nectar feeders. In one 2-hour period at Davis, five different species[7] of beetles were found feeding in the blossoms of pear. In cold or windy weather, flies are sometimes more numerous than bees in the blossoms. Leslie M. Smith[8] made a general survey of the insects in and around four pear orchards in the lower Sacramento Valley in May, 1930. He found flies in larger numbers than insects of any other group.

TABLE 4

Results of Culturing of Insects Collected from Pear Blossoms

Insect	Total number	Number contaminated with *Bacillus amylovorus*	Per cent contaminated
Ants	118	11	9
Aphids	54	16	29
Beetles	41	9	21
Flies	304	50	16
Thrips	150	65	43

The results in table 4 of culturing insects taken from pear blossoms, indicate in another way the potentialities of insects in the spread of blight at blossom time.

The unusual severity of blight in 1930 led some observers to question whether the blossom is the chief point of entry of the bacteria. As a

[7] *Attagenus piceus, Anthrenus* sp., *Diabrotica soror, Hippodamia convergens, Orsodacne atra* (identified by E. C. Van Dyke).

[8] Unpublished data.

result, counts were made in six orchards, mostly in the Santa Clara Valley, May 14 to 17, 1930. Of 100 infections in each orchard the following numbers seemed clearly to have taken place through the blossom clusters: 96, 97, 100, 100, 99, 100.

Some cultures of honeybees taken from blossoms are reported in table 2. These and other results outlined below, confirm Waite's early conclusion (68) that bees play a part in the dissemination of the bacteria from blossom to blossom.

The question as to whether the beehive might carry the bacteria from one district to another when moved for use in pollination was not answered by the earlier work. Four sets of experiments are now available bearing on this point representing work in New York (35), Ohio (37), and California. These have been called to the attention of California pear growers (63) and will not be treated in detail here. Trees were covered by tents in which the beehives were confined. All the experiments indicated that the bees carried the bacteria from blossom to blossom if the bacteria were first introduced into blossoms inside the tent. When, however, the hive, presumably contaminated, was removed and immediately enclosed with another tree, no blight resulted in any instance. Even when the hive was directly contaminated (in the Ohio experiments) by pouring a culture of the bacteria over the bees, comb, frames, etc., and then enclosed with a blossoming apple tree, no blight followed.

Some workers (16, 32, 65) have concluded that splashing rain is important in dissemination from blossom to blossom. Little evidence is available in support of this conclusion and it now seems more reasonable that the effect of rain is chiefly indirect, providing conditions favorable for infection after dissemination has taken place (60). This point is treated in more detail later in this bulletin.

Occasional workers have put forward the hypothesis that wind is capable of disseminating the bacteria. No satisfactory evidence has been presented in support of this hypothesis.

Dissemination of the Organism to Terminal Shoots.—Occasionally in California pear orchards there is considerable spread of blight by sucking insects to the young terminal shoots. Under exceptionally humid conditions, the bacteria spattered from oozing infections probably enter the leaves or shoots directly without the aid of insects (18, 32). Terminal infection usually occurs later than blossom infection, if at all. Among the insects[9] which have been shown by experiment to be capable of inoculating terminal shoots of pear and apple, aphids and plant bugs are

[9] *Aphis avenae* (grain aphid) (8), *Aphis pomi* (green apple aphid) (54), *Empoasca mali* (apple leafhopper) (8), *Lygus pratensis* (tarnished plant bug) (55), *Adelphocoris rapidus* (56), *Campylomma verbasci* (56), *Orthotylus flavosparsus* (56), *Plagiognathus politus* (57), *Poeciloscytus basalis* (56).

outstanding. The first of these are seldom seen in large numbers in the pear orchards of California. The plant bugs are more common and may reach large numbers on favorable host plants such as alfalfa and certain weeds. Leslie M. Smith[10] found the tarnished plant bug in large numbers in 1930 in two orchards with covercrops and in appreciable numbers in two clean-cultivated orchards of the lower Sacramento Valley. He demonstrated again by experiment the ability of this insect to transfer the blight bacteria to terminal shoots.

Dissemination of Blight Bacteria to Wounds.—The possibility of carrying the bacteria to open wounds by tools, ladders, shoes, cultivators, and other agencies has been emphasized by most investigators. Pruning shears have been under suspicion and rightly so, although much of the blight attributed to spread by shears is actually due to failure to cut ahead of or below the margin of the infection ("short cuts"). Cases have been seen in California and elsewhere in which hail undoubtedly opened the way for infection, but insects probably carried the bacteria to the wounds in most cases. Whether infection takes place through inoculated wounds will depend on the vigor of the tree, the age and type of wound, and the temperature and humidity. In general, any wound which admits the bacteria deep into the bark is much more likely to lead to infection than an open wound which dries quickly.

In one experiment started on May 21, 1930, in comparatively dry weather, 50 shoots were cut off in one and two-year-old pear wood with contaminated shears; 4 of these became blighted. Twenty-five ragged wounds were made in larger branches by gouging with a knife and were wet with a water suspension of the blight organism; 1 infection resulted. Twenty-five smooth open wounds made by cutting off the outer bark were inoculated in the same way; no infection developed in these. Of 10 shoots inoculated at the same time by puncturing with a contaminated needle, 9 became infected.

To obtain information on the readiness with which the bacteria are carried by tools to wounds in winter, 135 inoculations were made in pear bark by stabbing with a contaminated knife on January 28 and February 13, 1932 (Sacramento County). No infection resulted.

While these results support the observations of careful workers that infection through wounds inoculated by tools is rather infrequent, there is no warrant for omitting the treatment of tools and wounds with a germicide even in winter.

With the discovery of the blight bacteria in the soil (1), greater interest naturally attaches itself to the possibility of direct infection through wounds in the roots. During the winter of 1931–32 an oppor-

[10] Unpublished data.

tunity was afforded to examine a considerable number of uprooted trees in orchards of Sacramento County. Of 68 trees with infected roots only 5 to 8 were found which could not be accounted for by entrance by way of the trunk or root suckers.

Wounds in leaves and stems become closed to invasion by the blight bacteria in 36 to 72 hours (7). Several experiments were therefore made to determine whether wounds in the roots behave in a similar manner. In the first, 100 dormant seedling pear trees were wounded by a deep cut with a knife toward the base of the tap root. Twenty-five of these trees were then inoculated at once by applying a liquid culture of the bacteria to the wound. All of the 100 trees were then planted in loam soil in the greenhouse. On the second, fourth, and sixth days the three remaining lots of 25 trees each were successively removed from the soil (with care to avoid making fresh wounds), inoculated as above, and replanted. The numbers of infections for these four lots were 7, 4, 0, and 0, respectively.

Again two lots of pear seedlings growing in boxes out of doors were wounded on the main tap root 1 to 2 inches below the soil surface without disturbing the lower part of the root system. After replacing the top soil, one lot was inoculated at once, and the other 3 days later, by flooding the soil with a liquid suspension of blight bacteria. In the first lot, 5 of the 47 trees became infected, but none of the 31 trees in the second lot developed any symptoms.

A third experiment was made with pear seedlings in the third year from seed, growing in the field at San Jose. One hundred trees in one lot were wounded on the main tap root 3 to 6 inches below the ground line, after which the soil was replaced. Three days later 100 trees in a second lot were similarly wounded. Immediately afterward both lots were inoculated by pouring the bacteria in water on the soil beside the trunks. One month later there were no infections in the first lot and 10 in the second.

In another experiment, 100 seedling trees at San Jose were inoculated through needle punctures 2 to 4 inches below the ground line. At the same time 100 trees were inoculated by the same method on the trunks a few inches above the soil. Fourteen trees of the first lot and 11 of the second became infected.

It is concluded that infection of pear roots takes place rather readily through fresh wounds but infrequently on wounds 3 days old or older.

FACTORS WHICH INFLUENCE THE DEVELOPMENT OF FIRE BLIGHT

While the blight bacteria are the primary agents in producing the disease, the inception and development of blight are strongly influenced by a number of other factors.

Effect of Light on the Organism and on the Disease.—The bacteria are killed by exposure for 10 minutes to direct sunlight (69). The indirect effect of light on the disease, however, is apparently slight. Three experiments were made, two with *Pyracantha angustifolia* and one with pear seedlings, in which half the plants, 8 to 40 in number, were kept in deep shade or complete darkness for 2 to 15 days before inoculation. In one test, the shading was continued to 3 days and in another to 15

TABLE 5

RELATION OF GROWTH STAGE OF THE PLANT TO SUSCEPTIBILITY TO BLIGHT

	Duration of experiment, days	Inoculated at	Number of shoots	Number blighted	Average length of blighted parts, inches
Pyracantha angustifolia	16	Tip	10	9	4.9
		Base	10	9	2.3
Seedlings of Winter Nelis pear	10	Tip	10	6	3.9
		Base	10	6	1.2
Seedlings of Beurre Hardy pear	21	Tip	75	67	2.1
		Base	75	37	1.7

days after inoculation. In the third, all plants were equally exposed to light after inoculation. The results were similar in the three experiments. The newer growth was blighted somewhat more rapidly on shaded plants but the older parts, on the same plants, were, if anything, less readily killed.

Relation of Vigor and Growth Stage of the Tree to Blight.—It has long been recognized (4, 7, 10, 35, 58, 69) that fire blight is favored by those conditions which induce rapid and vigorous growth of the tree. Withholding cultivation, fertilizing, and pruning when blight is severe has become common practice in some districts. While this alone is not a feasible control method for blight, it does reduce the severity of the disease. The close relation between growth condition and susceptibility is illustrated by the results of inoculations at the tip and at the base of the current season's shoots on seedlings of pear and *Pyracantha angustifolia* (table 5). The more actively growing terminal part of the shoot became blighted more rapidly, and in the large-scale experiment that was conducted in the field, more often, than the basal part of comparable shoots. Other small-scale experiments indicate that the same relation exists in *Pyracantha gibbsii yunnanensis* and in toyon. A few pears (Douglas, Orel, and Surprise) appeared to be more resistant in the young shoots than in the trunks, according to Reimer (40).

Influence of Temperature.—Blight may be affected by temperature in a number of ways directly or indirectly. The temperatures of any given winter determine to a large extent the duration of the next blossom period and, of course, the longer the blossom period the greater will be the chance of inoculation in the blossoms. Thus, in 1930 after relatively high temperatures, particularly in February, the blossom period of Bartlett pear at Davis extended over 23 days as compared with 13, 13, and 12 days for the three succeeding years.[11] High temperatures in late winter are also favorable to blight in a more direct way[12] in that the overwintering cankers are stimulated to enlarge and to produce ooze which may reach the blossoms of early flowering plants and thus build up reservoirs of bacteria before pears come into blossom.

TABLE 6

EFFECT OF AIR TEMPERATURES ON BACTERIA IN BLIGHTING TISSUES

	Diameter of shoot, inches	Temperature, ° Fahrenheit	Duration of exposure. hours	Result*
Cotoneaster pannosa	1/16	100	4	+
	1/16	118	4	+
Pyracantha angustifolia	1	117	6	+
Pear	1/4	122	12	–
	1/8	140	½	–
Cotoneaster salicifolia	1/16	140	½	+
			1	–
Apple	3/16	140	½	+
	4/16	140	1	–
	3/16	158	½	–
	3/16	158	½	+

* The + sign indicates that the organism was not killed.

Blight is essentially a warm-weather disease. The most favorable temperature is apparently 70° to 80° F (7). The optimum temperature for the growth of the bacteria themselves as determined in the work of this laboratory is about 83° F.

Many growers and others in California have been under the impression that the higher summer temperatures of some of the interior valleys are sufficient to stop the development of blight. Since the bacteria are killed by an exposure of 10 minutes at 120° F when tested by the usual laboratory method and since temperatures of 115° to 120° F are

[11] Figures from W. P. Tufts.

[12] Of 84 seedling pear trees inoculated in the trunks at Berkeley on November 6, 1931, at least 9 had developed cankers before March 8, 1932. The largest of these cankers were 10 to 12 inches in length.

sometimes encountered in the warmer valleys, the effect of high air temperatures on bacteria which are inside the tissues of susceptible plants was studied in a number of tests. Infected plant parts or entire small plants were exposed to controlled air temperatures for different periods of time (table 6). The condition of the bacteria at the end of the exposure was determined by inoculation into susceptible fruits or shoots. All of the shoots indicated in the table were actively blighting at

TABLE 7

INFLUENCE OF WET AND DRY SOIL ON INFECTION OF POTTED PLANTS OF PYRACANTHA ANGUSTIFOLIA; RECORDS 14 DAYS AFTER INOCULATION

Test No.	Soil moisture	Number of shoots	Number blighted	Average length of shoot, in.	Average length of blighted part, in.
1	High	17	16	11.8	6.6
	Low	16	11	11.7	3.5
2	High	18	18	11·0	5 2
	Low	17	17	11.4	2.3

the time of heating. Judging from the abundance of bacteria in cultures and amount of oozing after heating, it is probable that the bacteria survived in some of the plants which are reported as negative in the table. At any rate, bacteria in the plant tissues are distinctly less affected by high temperatures than in liquid culture media. The bacteria inside the bark can apparently withstand air temperatures well above anything on record for the pear-growing districts. One lot of 5 blighted (but dormant) pear shoots $\frac{4}{16}$ to $\frac{7}{16}$ inch in diameter was collected in mid-February and exposed for 1 to 5 hours at 132° F. Living blight bacteria were not found in any of these after heating.

An explanation of the observed slowing of canker enlargement in the orchard with the advent of warm weather may be found in the fact that warm weather in California is usually also dry weather, which is distinctly unfavorable for blight. There is, of course, the possibility that high temperatures may in some indirect way retard the development of blight. This point perhaps deserves further study.

Influence of Water in the Soil.—From field observations investigators (4, 5, 67) concluded many years ago that abundant water in the soil favors the development of blight. Few, if any, actual experiments seem to have been made on this point. Two experiments were made in the greenhouse in the course of this work in which potted plants were watered alike until the time of inoculation. Thereafter one lot in each

case received ample water while another was dried as soon as possible to near the wilting point, close to which it was maintained until the end of the experiment. It is evident (table 7) that a shortage of water reduced the rate of development of infection and apparently also the number of infections from a given number of inoculations.

Experiments in the field are needed to show more clearly the extent of the influence of soil water on the development of blight.

Influence of Atmospheric Humidity.—The progress of blight after infection is established is favored by high relative humidity of the air (80 per cent or higher). This has been shown by carefully controlled experiments (7, 47) and may be verified by observation in the orchard when temperatures are favorably high.

Probably the most important relation of atmospheric humidity to blight is that which determines the concentration of sugars in the nectar and the amount of nectar in the blossoms. It was shown by earlier workers (6) and more recently in California (60, 66) that the volume of nectar in a blossom increases and the concentration of sugars in the nectar decreases with rising atmospheric humidity. Thus, the amount of nectar may vary from no visible liquid to a large drop in each blossom, and the concentration of sugar may vary from 1 or 2 per cent to 55 per cent or higher. The more concentrated sugar solutions (such as are found in blossoms in dry weather) not only are unfavorable to the development of bacteria, but also weaken their virulence so that they are feeble or entirely impotent in the production of blight. On the other hand, a culture solution containing only 1 or 2 per cent sugar (the percentage in pear nectar in practically saturated atmosphere) favors the rapid development of the more virulent blight bacteria and furthermore[13] soon restores the virulence of the weaker forms (60.) Several tests were made in which detached blossoms were inoculated and part of each lot was kept at high humidities while part was kept in the dry laboratory atmosphere. The blossoms in humid air blighted freely while those in dry air developed little or no blight (60).

The observed (36) decline in susceptibility of blossoms with increased age should be studied in relation to the quantity and quality of nectar present at different blossom stages.

The close relation between atmospheric humidity and the development of blight in the orchard is also suggested by the weather which has prevailed at times of severe outbreaks of blight. Unfortunately only a few records of atmospheric humidity are available. Those which are at

[13] Ark, P. A. Variability in the fire-blight organism, *Erwinia amylovora* (Burrill) Comm. S.A.B. Thesis for the degree of Doctor of Philosophy, University of California, 1934. (Typewritten.) Copies on file in the University of California Library, Berkeley.

hand show that in 1930 at the Oakdale[14] station the humidity was unusually high at certain periods, notably in the early part of May. Although the rainfall was below normal at Sacramento, it was distributed so that showers fell on 13 of the 26 days from April 12 to May 7, 1930.

A severe local outbreak in the Bereyessa Valley in 1932 was accompanied by frequent light showers. Official weather records for that locality are not available.

In 1933, blight was rather severe in a small area in Sonoma County near the weather station at Graton. The rain at that station in May was more than double the normal, and most of it fell on 8 of the first 11 days of the month.

In 1934, a period of about 5 days of high humidity occurred in the latter part of March over a considerable part of northern and central California. Several orchards in El Dorado and Lake counties which were near full bloom at this time were severely affected. Most of the Bartlett pear orchards in the lower Sacramento Valley had completed the blossom period at this time and early infections were not numerous in this district.

CONTROL OF FIRE BLIGHT

The control of blight remains, perhaps, the most difficult operation in the management of a pear orchard and is seldom accomplished by any except those who so regard it.

The Orchard Site and Choice of Varieties for Planting.—Since the pear is already overplanted, new orchards are not likely to be numerous in the next few years. The blight hazard may be appreciably reduced by isolating the planting as far as feasible from susceptible trees and shrubs, particularly those over which the grower has no control. Within the orchard itself, future trouble may be forestalled to some extent by avoiding varieties which come into blossom just prior to the blossom period of the principal variety of that orchard. There is little choice between the principal commercial varieties on the basis of blight resistance. All the varieties commonly planted in California are distinctly susceptible, though some, as the Winter Nelis, Anjou, and Comice, are somewhat less so than such varieties as Bartlett, Beurre Hardy, and Bosc.

On the assumption that the ultimate solution of the blight problem lies in the development of resistant varieties, something over forty thousand seedling trees were planted at San Jose in 1932. The seeds came from trees of Beurre Hardy and Winter Nelis which were exposed to open pollination by Bartlett. The seedlings are inoculated several

[14] Records are taken from the official reports of the Weather Bureau of the United State Department of Agriculture.

times each year with the blight bacteria. The more promising of the survivors will be brought to fruiting.

Rootstocks.—The development of an immune and otherwise satisfactory rootstock would go far toward the solution of the blight problem. Practically all of the known pear species have been studied with this problem in mind. Outstanding in this field is the work of the Southern Oregon Branch Station (40). No species has as yet shown sufficient promise to be offered for extensive planting.

The extensive planting during recent years of the Japanese stock (*Pyrus serotina*) has lead to unsatisfactory results in several ways: While the species as a whole is much more resistant than the French seedlings (*Pyrus communis*), individual roots are occasionally highly susceptible. The promise of vigor shown by young trees on Japanese stocks has not been fulfilled in the mature trees. These stocks tend to influence unfavorably the shape of fruit (64). Most serious of all, they predispose the fruit to black-end (11). The fact that these faults were not apparent until the trees were several years in the orchard will doubtless lead to a justifiable caution in the adoption of new stocks in the future.

The oriental species *Pyrus calleryana* and *P. ussuriensis* have been planted as stocks in a few orchards in California. Although the former may prove to be of some value, the present tendency is away from these species, owing in part to the unfortunate experience with the Japanese species *P. serotina*.

The most popular stock combination in California at present is French seedling root with the variety Old Home supplying the trunk and main branches, on which is budded the desired fruiting variety. Few if any of these trees have reached an advanced age and their future cannot be predicted without reservation. However, there is no more promising stock in sight at the moment. The Old Home is highly resistant to blight (40), although young trees are occasionally killed when the trunk is invaded from below through the susceptible root. It is susceptible to a fungus crown rot (apparently caused by a species of *Phytophthora*) and in at least one instance[15] has been rather severely affected by the blast disease. But these diseases have not thus far been generally prevalent in the variety.

A method of searching for new stocks has been adopted at this station which should avoid some of the pitfalls which are to be expected when stocks are started from seed. In orchards forty to sixty years old and presumedly on French roots, trees are selected which are of good appearance and which show no evidence of blight on the stock. Shoots (suckers) from the stock are collected and propagated by grafting on ordinary

[15] Verbal report of E. E. Wilson.

seedling roots. Thereafter they are tested for resistance by repeated inoculation. Such shoots from approximately one thousand trees were propagated in 1933 and a smaller number in 1932. The results of preliminary inoculations lend some encouragement to the further use of the method. When a sufficiently resistant individual is found, it will be propagated vegetatively.

Control of Blight by Spraying.—Many workers from the early days of blight investigation to the present time have attempted to control the disease by spraying. Bordeaux mixture has been used in most of the experiments. Some investigators (25, 27, 28, 41, 43, 53) have obtained considerable reduction in blight while others (31, 32) have observed no benefit whatever.

Several pear growers in 1932, 1933, and 1934 in coöperation with the writers made spraying tests in which weak bordeaux mixture, copper ammonium silicate (Coposil), copper resinate, and a zinc sulfate and lime mixture were used. There was not sufficient blight in any of the test plots to permit any conclusive estimate of the value of the treatments.

One grower, A. F. Veerkamp, in El Dorado County, with whom the writers were not in touch at the time, obtained a considerable reduction in number of infections in 1932 by an application of bordeaux mixture while the trees were in full bloom. In this case the number of infections cut from the unsprayed trees was about forty times that from the neighboring sprayed trees.

In another orchard in the same county in 1934 part of the trees were sprayed with 1–1–50 bordeaux mixture in the open blossoms immediately before a 5-day period of showers and high humidity which began on March 23. On April 23 the blighted spurs on 5 sprayed Bosc trees were 2, 4, 3, 0, and 2, respectively, while the blighted spurs on 3 unsprayed trees were 137, 207, and 195. In a part of the orchard sprayed immediately after the humid period there was no perceptible reduction in blight. Another grower in the same district recalls a similar experience in 1931.

Most of the favorable results have followed spraying into the open blossoms, and there is considerable evidence to indicate that success depends upon applying the spray at or shortly before the time at which dissemination takes place.

Considering the erratic results and the possibility of spray injury, there is little reason at present to suggest the general use of spraying for the control of blight in California pear orchards. Nevertheless this method in conjunction with a better understanding of the time of dissemination bids fair to make the next important advance in blight con-

trol. For those who wish to use a spray in an experimental way, it is suggested that a bordeaux mixture be used which is low in copper sulfate and comparatively high in lime, as 1–5–50. It is desirable that a record be kept of the time of spraying with reference to the stage of the blossom and that every effort be made to anticipate humid weather during the blossom period.

Biological Control.—Considerable time has been given by Parker (35) and by the writers to a search for bacteria other than the blight organism which may be introduced into blossoms to inhibit the development of the blight bacteria. Several have been found which are strongly antagonistic to the blight organism in laboratory cultures but none thus far has consistently caused more than a slight reduction of blossom blight in the orchard.

Cultural Practices in Relation to Blight.—As has been stated earlier, such practices as clean cultivation, heavy pruning, and liberal applications of water and fertilizer favor the progress of fire blight. Neglect of these practices does not constitute a working control program though it has been tried many times. However, moderation in these things can be practiced with profit, particularly in times of low prices. The extent to which cultural practices should be modified in the attempt to control blight will vary from orchard to orchard and is of necessity determined by each individual grower on the basis of such factors as the amount of blight present, the existing vigor of the trees, the cost of the operation, and the return for the crop. At best the cultural operations cannot be more than supplementary to the more direct methods of control. Evidence was presented earlier in this bulletin to show that roots may be infected directly through fresh wounds. It is advisable therefore that whenever feasible the land be prepared for irrigation at least 3 days before the water is turned into the orchard.

Treatment of Blight Cankers.—There are three methods of canker treatment now in general use in addition to that of removing the affected branch altogether. Some growers use one or another of these methods almost exclusively, while others employ all the methods, according to the type of canker, season of the year, and other factors.

The first method, frequently known as scraping, consists in cutting away all the discolored or watersoaked bark down to the wood and in addition a portion of the living bark on all sides of the canker. The distance of the cut beyond the visible margin of the canker has always been a moot question which cannot be answered in general terms. With completely dormant cankers, 1 inch at the sides and 2 or 3 inches at the ends is a safe distance. On the other hand, with vigorously active cankers, 12 or even 18 inches may be short of the required distance. A given canker

may be active at one end and dormant at the other, or active in January and dormant in August. The bacteria, in all or nearly all cankers, are present in the apparently sound bark beyond any visible discoloration, and the distance beyond is usually greater in young branches than in old, greater in vigorous than in weak trees, and greater in warm or moist than in cold or dry weather.

The experienced blight operator varies the distance of his cut with each individual canker. He is guided principally by two things: the amount of cracking in the bark at the margin of the canker, and the abruptness of the change from dead brown bark to the light-colored living bark. That is, when these features are most pronounced the shortest cut beyond the visibly affected bark can be made. For the inexperienced operator, it can only be stated that a large portion of the failures in eradication of blight cankers are due to short cuts. All cut surfaces and the tools used in cutting should be treated with a good germicide. The writers prefer a solution of mercuric chloride and mercuric cyanide.[16]

The tools used in scraping are to a considerable extent a matter of individual preference. A convenient type is shown in figure 4*C*. The scraping method is particularly applicable to large deep-seated cankers such as are more often found in fall and winter.

The method known as scarifying is similar to the preceding but differs essentially in that only the outer bark is removed except where the inner bark actually shows discoloration. In the pear orchards in California blight often advances for as much as 1 or 2 feet in the outer bark before the inner bark is affected. This fact makes possible the profitable use of the scarification method. Here again the cut surface is treated with

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[16] *Mercuric chloride—mercuric cyanide disinfectant.*—These two poisons are sold at most drug stores in tablet or powder form. Either form may be used, but the tablets are more convenient for small quantities and they dissolve more easily. The tablets of mecuric chloride referred to below are of the size containing 7.3 grains. A solution containing glycerine, about 10 per cent by volume, wets the tools better and evaporates more slowly than a water solution. A solvent containing three parts glycerine to one part of water has been used extensively and is entirely satisfactory except for the additional cost. The proportion of glycerine to water can safely be varied considerably but the proportion of the mercury compounds to the solvent should not be changed without good reason. The following disinfectants are based on a strength of 1 part of each ingredient to 500 parts of solvent.

A solvent containing approximately 10 per cent glycerine can be made as follows: For 1 pint use 14 ounces water and 2 ounces glycerine. For 1 gallon use 7 pints water and 1 pint glycerine.

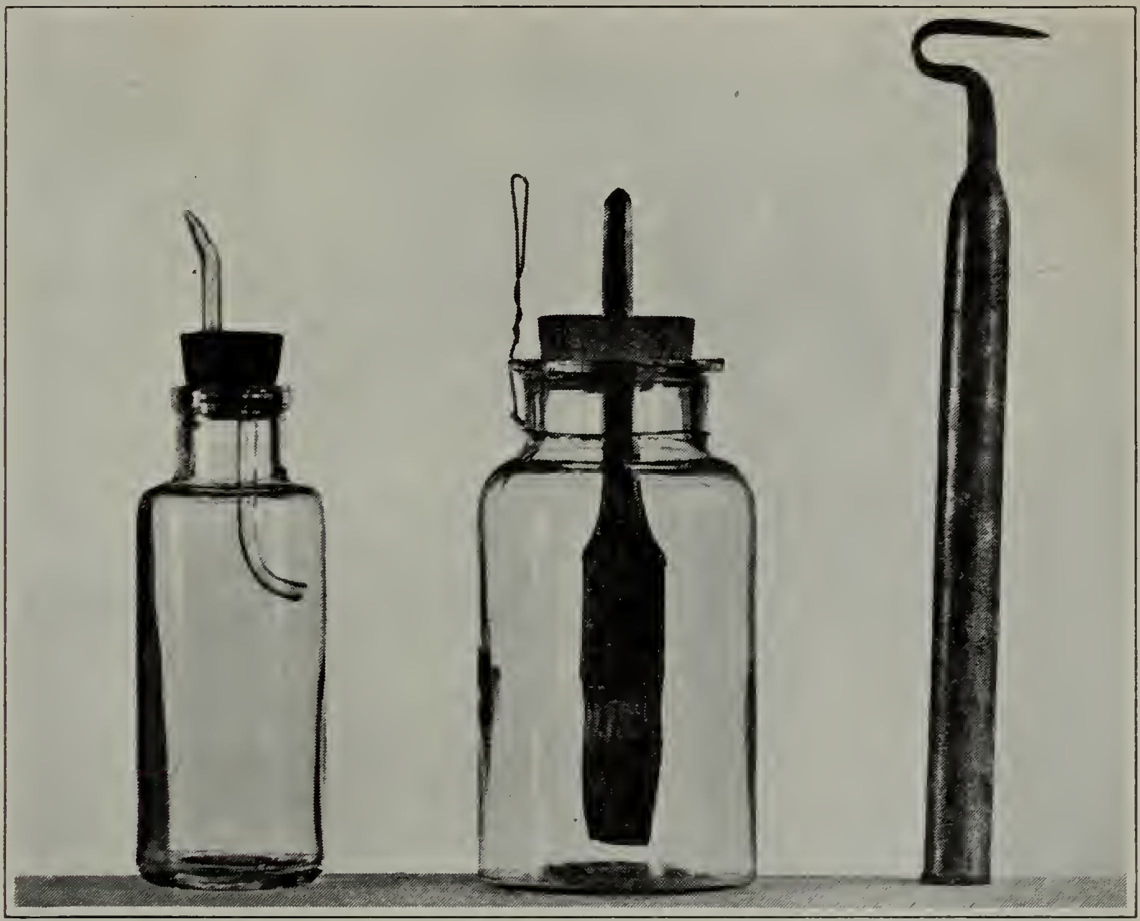
To make 1 pint of disinfectant add 2 tablets mercuric chloride and 2 tablets mercuric cyanide to 1 pint of solvent.

To make 1 gallon of disinfectant add 16 tablets or ¼ ounce powdered mercuric chloride and an equal quantity of mercuric cyanide (also either tablets or powder) to 1 gallon of solvent.

This disinfectant should be kept only in glass or earthenware containers (fig. 4, *A*, *B*). **It is a deadly poison.** The same antidote may be used as for zinc chloride; see page 33.

the mercury solution. This method is most useful in early and midseason when most of the cankers are small and not yet deep-seated.

The third method (13), which may be designated as the drenching method, consists in applying a penetrating chemical solution to the un-



A B C

Fig. 4.—*A*, A wash-bottle type of container for use in pouring solution onto bark in the drenching method of canker treatment. The glass tubes extend through the stopper, the tube below admitting air into the bottle as the liquid is poured out of the upper tube. This container was introduced by L. H. Day. *B*, A convenient container for disinfectants, with brush attached to cork. *C*, A useful scraper. The blade, including the curved portion, is sharpened on one edge and at the tip.

cut surface of the bark. This method involves a principle which has seldom been successfully employed in dealing with plant diseases, namely that of true disinfection, or killing the organism in the tissues after infection is well established without killing the plants. Assuming an ideal solution, the method has certain obvious advantages among which are increase in speed, reduction in labor, and saving of bark which would otherwise be cut away (figs. 5 and 6).

Some of the characteristics desirable in such a solution are: (1) penetration into the affected bark without extensive injury to healthy bark; (2) ready spreading on the surface of bark; (3) little corrosion of metals, fabrics, and the hands of the user; (4) stability in solution; (5) moderate cost; (6) one of the following: (*a*) direct toxicity to the

bacteria; (*b*) arrest of activity of the disease until the tree is able to overcome it; or (*c*) alteration of the bark so that it becomes unfavorable for the development of the bacteria.

In the development of new solutions, a large number of tests are necessary before any definite conclusions can be drawn as to the effi-

Fig. 5.—Severely blighted Bartlett pear tree treated June 2, 1930, by cutting off the smaller affected branches and drenching the 34 cankers on larger branches. One active canker (of those treated) was found on July 23. (Photographed June 2, 1930.)

ciency of the solution. The effectiveness of a given strength of solution may vary with the size and age of the branch, size of canker, variety of pear, the district, and the weather, especially the temperature. With most, if not all solutions which have been tested, the margin of safety between the killing point of the bacteria and that of the bark is comparatively narrow. A fault which is inherent in the method irrespective of the solution used, is the increased difficulty of inspection after treatment to determine whether or not the disease is arrested.

After testing a large number of materials, Day (12, 13) introduced the zinc chloride solution, which has been used extensively in certain pear districts of the state, notably in the Sacramento Valley. The use of this solution is described in detail in Extension Circulars 20 and 45. These circulars are now out of print, but many copies have been dis-

tributed in the state, and most city and county libraries have them on file. The prospective user should consult them if possible unless he is already familiar with the method. The formulas for the preparation of solutions most commonly used are given below.[17]

This material is poisonous and should be kept out of the reach of

Fig. 6.—The tree shown in figure 5 photographed seven weeks later.

children and farm animals. In case of accidental ingestion use white of egg beaten up in water, or olive oil, or a large amount of water or milk; induce vomiting; and send for a doctor.

[17] Zinc chloride solutions are prepared by dissolving zinc chloride powder in a *solvent* consisting of 7 pints of denatured alcohol, 2 pints of water, and 3 ounces of hydrochloric acid, making approximately 9 pints of solvent. It must be prepared in glass or enamelware and stored in tightly corked bottles.

9 lbs. zinc chloride in 9 pints solvent makes a 53 per cent solution.
6 lbs. zinc chloride in 9 pints solvent makes a 43 per cent solution.
4 lbs. zinc chloride in 9 pints solvent makes a 33 per cent solution.

The solutions are more easily prepared by first dissolving the zinc chloride in the 2 pints of water by boiling, then adding the acid, and lastly pouring this mixture into the denatured alcohol.

A simpler method of preparing the weaker solutions is to dilute the stronger solution with the solvent, or with denatured alcohol:

1 gal. of 53 per cent plus 3 pints of solvent makes a 43 per cent solution.
1 gal. of 53 per cent plus 1 gal. of solvent makes a 33 per cent solution.
1 gal. of 33 per cent plus 4½ pints of solvent makes a 23 per cent solution.
1 gal. of 33 per cent plus 13 pints of solvent makes a 15 per cent solution.

The above formulas are only approximately accurate, but are sufficiently so for practical purposes.

The most satisfactory strength of solution should be determined by trial in the individual orchard. The solution is brushed onto the bark or poured from a container of the wash-bottle type (fig 4*A*). The bark should be thoroughly wet, and with rough bark the outer scales should be removed before the application is made. Nails or other markers at the ends of treated cankers are essential to later inspections.

This solution has been used with encouraging results on fire blight of apple in Tennessee (26). Preliminary tests on apple and pear in several other areas (7, 31, 35) have not been conclusive.

A considerable number of other materials have been used by Parker (35), most of them in New York and a few in California. Among these, cadmium sulfate and cadmium nitrate offered some promise, but a satisfactory solution of these materials has not yet been perfected.

During 1932 and 1933, the writers tested over one hundred materials or combinations, mostly on a small scale. Since the results were largely negative, or inconclusive, these will not be presented in detail. The solvent in most cases consisted essentially of ethyl (grain) alcohol, glycerine, and a small amount of acid, either acetic or hydrochloric. All of the experiments were made in orchards in which untreated cankers were available for comparison at all times.

Solutions of cadmium sulfate and sodium salicylate stopped 80 to 100 per cent of the cankers treated in spring and summer but were distinctly less effective in fall and winter. Cobalt nitrate solutions have given more consistent results. While none of these materials has thus far shown sufficient promise to be offered for extensive use, the search for improved or superior materials should be continued.

The drenching method will probably eventually replace largely or entirely the methods of scarification and scraping. At present, however, the most useful function of the drenching method lies in the early treatment of the numerous small cankers which accompany an outbreak of blight.

A Seasonal Program of Fire-Blight Control.—For convenience in actual use the principal control operations are outlined below in more or less chronological order.

The dormant season from November to March is by far the most important period of the year in the control of blight. The earlier part of this period is preferable in several ways to the latter part for the winter work. The leaves on injured branches or trees turn yellow or red earlier than those on uninjured trees, and this fact frequently leads the blight operator to trunk and root infections which would otherwise escape notice. Since the cankers may continue to enlarge during the warmer weather of the winter, a considerable saving of trees or branches is

effected by early treatment. It is advantageous to complete the blight work before pruning begins because pruning increases the difficulty of finding the canker. In any event, removal of all infections from twigs, branches, trunks, and roots before the first pear blossoms open is highly important. Susceptible trees, such as pear and apple, in the immediate vicinity of the orchard should be as nearly free from blight as possible and, when feasible, should be removed altogether.

A *B*

Fig. 7.—*A*, The trunk of a pear tree with affected bark but no external symptoms; *B*, the same trunk with outer bark cut away to show dead area killed by blight.

The common practice of gouging into the bark around the base of the trunk on older trees to detect blight is a dangerous one in any except expert hands but is essential to a thorough inspection and is supported by long experience (51). Other important means of finding cankers in rough bark are the ooze and the blighted fruit spurs or shoots through which the bacteria usually penetrate the trunks and large branches. These are not always present, however (fig. 7).

Cankers on roots and crowns present a problem similar to that aboveground but more difficult. With the possible exception of very old and valuable trees, any trees on which the root system is more than half destroyed by blight are best removed. The danger of heavy loss is considerably lessened by removing the shoots and blossom spurs from the crowns, trunks, and lower part of the main branches before blossom time.

Immediately before the blossom period, a final inspection is made, during which cankers already treated should be examined for any sign

of activity and re-treated if necessary. Infected branches which are removed during the few weeks preceding the blossom period should be disposed of before the blossoms open.

For the treatment of cankers during the dormant period, most workers use the scraping method. The zinc chloride solutions have been used by some operators with satisfactory results. Scarification is not applicable to most of the infections encountered at this season.

During and immediately after the blossom period, frequent inspections are necessary to detect the first new infections of the season. The interval between inoculation and the appearance of symptoms (darkening, oozing, or wilting) will vary from 4 to 20 days; usually this period is 8 to 12 days. The number of blighted blossoms (including the late blossoms) provides a fairly definite forecast of the blight problem for the season. In some seasons the scattered late blossoms develop more numerous infections than the main crop of blossoms.

When blossom blight is found, the first concern should be with the infections on or near the trunks and main branches. These should be treated even at the cost of considerable delay in the removal or treatment of infections in the tops of the trees. This task calls for the best men available, preferably without ladders. Little time is required for the blight organism to travel from the blighted blossom through the spur into the bark of the supporting branch. Even if such infections are treated as soon as the blight is visible, removal or drenching of at least a small area of the bark around the base of the spur is frequently necessary. The same may be said of infections on young tender shoots growing out of trunks and large branches. It is here that the zinc chloride solution is most useful, particularly when infections are numerous. Scarification also finds its greatest use at this season.

After the trunks and large branches are taken care of, the blighted spurs and shoots on the upper and outer part of the tree are removed as promptly as feasible. Infections on branches less than 1 inch in diameter are difficult to treat successfully by any method except the surgical and are best cut off at once in most cases. Those on larger branches are dealt with by one of the methods of canker treatment already described.

During the weeks which follow the appearance of blight, the trees should be examined weekly or oftener for the treatment of new infections and inspection of those already treated. Blighted branches which are cut off at this season should be removed promptly from the orchard or destroyed (20). Also at this time greater care is necessary in the use of the mercury solution on tools and wounds, although, as is pointed out elsewhere, there is no good ground for laxity in this practice at any time of the year. Opinion varies as to the treatment of the numerous, appar-

ently healthy, shoots which spring up from the trunks and crowns of trees during the spring. The writers prefer the practice of removing these as early as possible. Some growers kill them with zinc chloride solution, which tends to prevent the development of new shoots from the same areas.

During an outbreak of blight, irrigation should be delayed as long as other considerations will permit and in any case the chance of root infection will be reduced by preparing the land at least 3 days prior to irrigation.

Blight-control work is commonly suspended for a time before and during the harvest. This involves no great risk of increase in the number of infections, but many of the cankers already established will continue to enlarge until they are treated or the tree is dead. Growers are sometimes lulled into a state of false security by the frequent stoppage of the more conspicuous infections (on smaller branches) in midsummer. At the same time the more dangerous cankers on trunks and large branches may be steadily increasing in size.

After the harvest of early pears in some seasons there may be a considerable crop of late blossoms which may develop numerous new infections toward the latter part of the season. The removal or treatment of all possible old infections in early and midsummer will obviously go far toward the prevention of these late infections.

Perhaps the most important single factor in effective blight-control work is the caliber of the blight operator. An inexpert or indifferent worker may actually increase the loss in the orchard by obscuring rather than removing the infections, by spreading the bacteria, and by cutting away bark or branches that would be saved by a competent man. An advantageous method of selecting men is to make each worker continuously responsible for the same rows or blocks of trees in the orchard.

A few growers have adopted with good results the practice of using scouts to find and mark the cankers, which are then treated by an experienced operator. Finding the cankers is the most difficult part of all blight-control work but is dependent more on agility and good eyesight than on long experience. This division of labor will doubtless be profitable in other orchards.

SUMMARY

The symptoms, manner of dissemination of the organism, and control of fire blight are outlined.

Thirty-four species of the rose family are added to the list of susceptible plants. There is evidence that the disease in severe form is limited to a small number of plants closely allied to pear and apple.

Spring sources of the bacteria outside the orchard seem to be of minor importance (though not negligible) in comparison with the cankers within the orchard.

When beehives were contaminated by confinement with inoculated blossoms and then enclosed with blossoming pear trees, no infection resulted.

Evidence is presented to show that high atmospheric humidity with or without rain is important in the establishment and development of blossom infection after dissemination has taken place. This seems to be due principally to the influence of humidity on the quantity and sugar content of the nectar.

The bacteria in blighted plant tissues are able to survive air temperatures above any which prevail in pear orchards.

Wounds in pear roots are closed to invasion by the blight organism within 3 days after the time of wounding.

A few growers have obtained marked reduction in blossom blight by spraying with weak bordeaux mixture in the open blossoms. This control measure is still in the experimental stage.

Established control measures and a control program are outlined.

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